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Characterization of Candidate Materials for Composite Cartridge Case

by Aristedes Yiournas, Brian M. Powers, Travis A. Bogetti, and William H. Drysdale

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14. ABSTRACT
Cased telescoped ammunition designs were developed for the Multi-Role Armament and Ammunition System that employed a composite cartridge case. Three candidate composite material systems are being considered for the application—50% chopped fiberglass/Nylon 12, 30% chopped fiberglass/ULTEM (a registered trademark of GE Plastics Corp.), and a continuous fiberglass/urethane. Each of these material systems was subjected to preliminary mechanical testing in order to characterize their basic material properties and to support finite-element modeling of the cartridge case/gun chamber during the firing cycle. Basic mechanical properties such as stress-strain curves, Poisson's ratio, and residual plastic deformation after unloading were obtained and are presented in this report.

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composite materials, cartridge case, characterization

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Contents

List of Figures

List of Tables

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1. Introduction

A cartridge case contains the propellant and ignition system necessary to launch a projectile from a gun and provides alignment to allow the projectile to enter the gun tube smoothly. After the firing cycle is complete, the case must be extracted from the gun chamber to allow the next round to be loaded.

Conventional breech loaded cartridge cases have traditionally been made of brass or steel. The case is inserted into the chamber of a gun, and the propellant is ignited. Relatively low pressure is needed to expand the case until it contacts the gun chamber wall, taking up the clearance designed between the case and chamber wall. From this point in the loading until peak pressure, the gun chamber provides the major part of the resistance to gun pressure.

The deformation of the gun chamber by the propellant pressure is completely elastic due to the residual stresses created in the gun tube by the autofrettage process. In contrast, the deformation in the case commonly contains a significant plastic component.

As the propellant pressure decreases in the chamber, both the case and chamber shrink elastically. The goal of the case design and material selection is to ensure that the plastic deformation is not allowed to develop to such a level that there is no clearance between the case and the chamber wall after all pressure has been exhausted.[1]

Further aid in the extraction of a conventional case is obtained by including a slight taper in the case and chamber wall. Then, any rearward movement of the case due to engagement of the extractor pins at breech opening further increases the clearance and assists smooth extraction.

Cased telescoped ammunition (CTA) was developed for use in the Multi-Role Armament and Ammunition System (MRAAS) swing chamber gun. This concept places additional design burdens on the cartridge case.

For the swing chamber gun, the round is loaded into the chamber in its rotated position. The chamber is then turned 90° so that it is aligned with the gun tube, and the round is fired. The chamber is then rotated back into the open position, and the spent cartridge is extracted by being pushed through the chamber by the loading of the next round.[2]

The cartridge must now seal both ends of the chamber, not just the breach end, as with conventional guns. This push-through feature for removing spent rounds means that the chamber

[1]U.S. Army Materiel Command. *Engineering Design Handbook: Ammunition Series, Section 4, Design Projection*; AMCP 706-247, July 1964.

[2]FC Munition Design Team Review. Picatinny Arsenal, NJ, 11 July 2000.

and case cannot be tapered to aid in extraction. Thus, the responsibility for ease of case extraction falls solely on case design (clearances, etc.) and material selection.

The material must deform without failing under firing pressures and elastically recover enough deformation so that the spent case can be removed by the force of loading. Since the gun chamber absorbs the majority of the propellant pressure, ductility and elastic recovery, rather than strength, are the important properties of the sought material.

2. Sample Materials and Test Preparation

Three composite material systems were evaluated for use in the CTA. They are fiberglass/Nylon 12, fiberglass/ULTEM,* and fiberglass/urethane. The Nylon 12 and ULTEM matrix composites used chopped fiberglass, while the urethane composites used continuous fiberglass laminates.

The fiberglass/Nylon 12 was supplied as a hollow tube of ~6° inches in length and 5.5 inches in diameter, made by injection molding. The wall thickness was 0.375 in. The fiber reinforcement consisted of chopped fiberglass of 50% weight. Narrow arcs were cut out and machined into rectangular blocks from which tensile test coupons were sectioned with a precision slot-grinder machine fitted with a diamond cut-off saw. This process and the tube coordinate system are illustrated in figure 1.

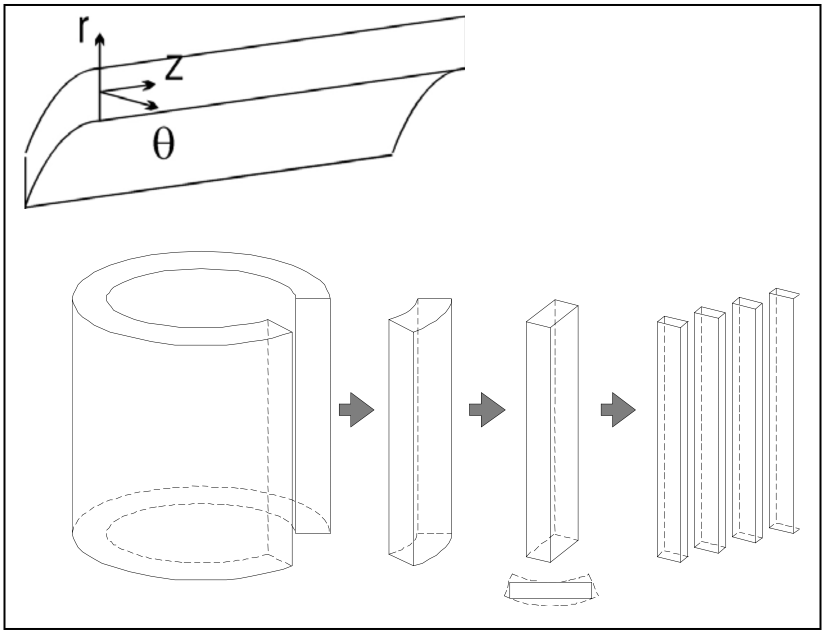

Figure 1. Illustration of tensile specimen sectioning from sample tubes and radial coordinate system with respect to tube arc.

*ULTEM is a registered trademark of GE Plastics Corp.

The 30% weight fiberglass/ULTEM was also supplied in two hollow tubes, with the effects of two manufacturing processes investigated. Both tubes had a diameter of 5.5 in and a length of 6 in. The first tube was made by machining an extruded fiberglass/ULTEM cylinder. After extrusion, the cylinder was machined to a 0.25-in wall thickness, and end-seal chevrons were placed on each end of the tube. The second tube was manufactured by injection molding and had a wall thickness of 0.375 in. This tube was supplied with no further processing after being injection molded. Samples from both the ULTEM matrix tubes were prepared by the same process outlined for the Nylon 12 matrix tube.

The fiberglass/urethane samples were manufactured by the hand lay-up of unidirectional fiberglass plies into flat panels with various laminates from which tensile coupons were sectioned directly. The manufacturing process took place at the U.S. Army Research Laboratory facility located in Aberdeen, MD. The four lay-ups manufactured were $[0°]_5$, $[90°]_{10}$, $[\pm 45°]_5$, and $[0°/90°]_5$. Test samples were cut from the flat panels using a slot-grinder fitted with a diamond cut-off wheel.

As was practical, all materials were tensile tested in the best accordance with ASTM D 3039.[3] This standard specifies whether bonded end tabs or friction tabs, such as emory cloth, are appropriate for random, discontinuous fiber composites. Where applicable, end-tab material was a fiberglass composite. Except for where specifically noted, Hysol[*] structural adhesive was used to bond the end tabs to the samples. An Instron[†] 4484 multipurpose test machine was used to perform tensile tests on all the samples, and cross-head displacement rates varied from 0.05 to 0.5 in/min, depending on lay-up as defined in the ASTM D 3039 standard. Table 1 summarizes the test configurations and loading rates for all test samples. Except where noted, all specimens were instrumented with strain gages to measure both longitudinal and transverse strain. Young's modulus and Poisson's ratio were determined from this data.

3. Test Results

Data from the Instron's load cell and a strain gage acquisition computer was reduced to stress vs. strain curves. It was found that all materials except for $[0°]_5$ and $[0°/90°]_{10}$ fiberglass/urethane exhibited a nonlinear softening curve. Tables 2 and 3 summarize all of the test results. Sections 3.1–3.3 discuss individual materials.

3.1 The 50% Fiberglass/Nylon

The first series of tests on the 50% fiberglass/Nylon 12 was not fitted with strain gages. Because calculation of strain from crosshead displacement was inaccurate, stress-strain curves could not be constructed for series 1. Tensile strength was determined and found to be ~7–8 ksi.

[3]ASTM D 3039. Standard Test Method for Tensile Properties of Fiber-Resin Composites, *Annu. Book ASTM Stand.* **2002**.
[*]Hysol is a registered trademark of the Dexter Corp.
[†]Instron is a registered trademark of the Instron Corp.

Table 1. Summary of tensile test configurations.

Material	Original Section	Dimensions (in)	End Tabs/ Adhesive/No.	Loading Rate (in/min)
Nylon series 1	3/8-in wall tube injection mold	4 × 0.31 × 0.13	2 tabbed (quick epoxy) 2 untabbed	0.05
Nylon series 2	3/8-in wall tube injection mold	4 × 0.29 × 0.09	3 tabbed (quick epoxy) 2 untabbed	0.025
Nylon series 3	3/8-in wall tube injection mold	4 × 0.33 × 0.09	6 tabbed (Hysol 9309)	0.025
ULTEM extruded	1/4-in wall tube machined	4.38 × 0.39 × 0.1	4 untabbed emory cloth	0.025
ULTEM injection molded	3/8-in wall tube injection mold	6 × 0.31 × 0.1	4 untabbed emory cloth	0.025
Urethane $[0°]_{10}$	~1/10-in sheet 5 plies	10 × 0.5 × 0.09	4 tabbed (Hysol 1C)	0.05
Urethane $[90°]_{10}$	~1/4-in sheet 10 plies	10 × 1 × 0.24	5 tabbed (Hysol 9309) 3 untabbed	0.5
Urethane $[\pm 45°]_5$	~1/4-in sheet 10 plies	10 × 1 × 0.22	5 tabbed (Hysol 9309)	0.25
Urethane $[0°/90°]_5$	~1/4-in sheet 10 plies	10 × 1 × 0.24	5 untabbed	0.05

Table 2. Summary of tensile test results.

Material System	Average σ_f Standard Deviation (psi)		Average E_o (psi)	Average ε_f (in/in)	Average Poisson's Ratio
Nylon series 1	7160	533	NA	NA	NA
Nylon series 2	7484	449	890,000	0.013	0.4
Nylon series 3	8220	882	812,000	0.018	0.45
ULTEM extruded	21525	1550	1,000,000	0.031	0.3
ULTEM injection molded	17340	869	1,048,000	0.024	0.35
Urethane $[0°]_{10}$	51870[a]	5106	6,100,000	End tab failure occurs before 0.01	0.4 (parallel to lamina)
Urethane $[90°]_{10}$	811	130	39,900	0.45	0.05 (parallel to lamina)
Urethane $[\pm 45°]_5$	8727[a]	488	60,600	0.42	1.0 (parallel to lamina)
Urethane $[0°/90°]_5$	15822[a]	968	1,754,000	End failure occurs before 0.01	0.25 (parallel to lamina)

[a] Value is not the true failure stress.
Note: NA = not available.

Table 3. Summary of residual strain after loading/elastic recovery.

Material	Nylon/Glass	ULTEM/Glass	Urethane [90°] (%)	Urethane [45°] (%)
Residual plastic strain	0.3%	0.2%	1.6	1.0
Unloaded form	90% fail load/ 1.4% strain	90% fail load/ 2% strain	4.6	4.5

Series 2 was fitted with strain gages, and stress-strain results are shown in figure 2. The samples had 0.75-in fiberglass/epoxy end tabs bonded with a common quick-set epoxy. Specimens 1 and 2 in figure 2 show drops in stress that correspond to the end tabs pulling away from the samples. The samples did not have transverse strain gages, so Poisson's effect was not measured.

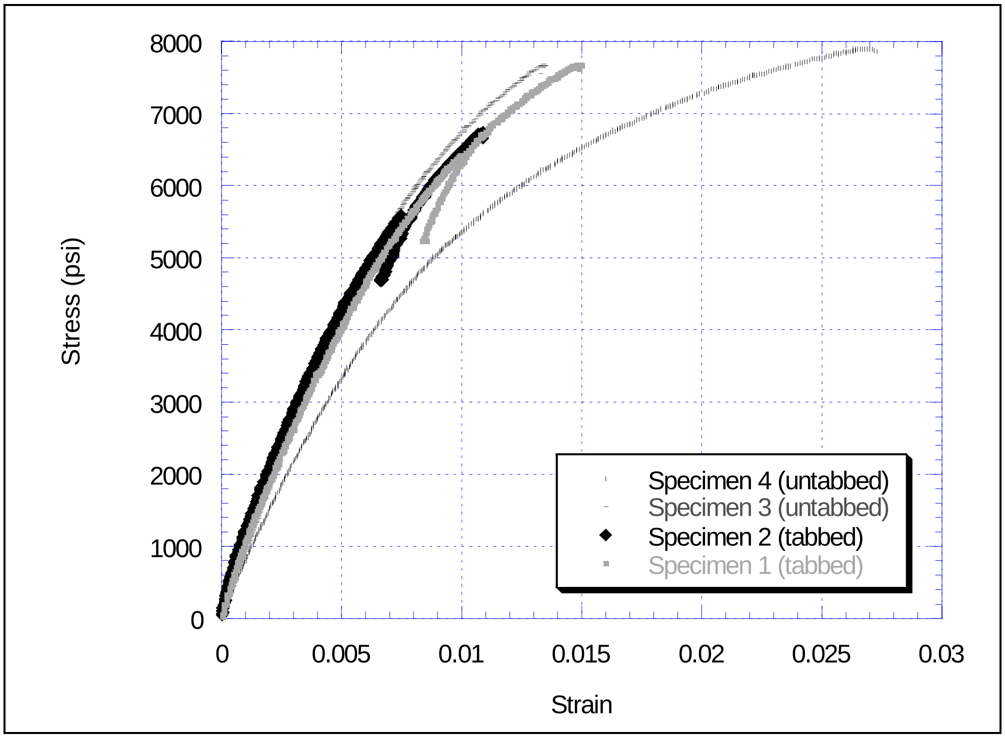

Figure 2. Illustration of tensile specimen sectioning from sample tubes and radial coordinate system with respect to tube arc.

To prevent the end tabs from pulling away, Hysol structural adhesive was used in series 3 tests. Despite this, the material did not strain greater than 2%. Biaxial strain gages accurate up to 5% were mounted on specimens, allowing the Poisson's ratio results in figure 3. The samples were also loaded and unloaded incrementally to measure residual plastic strain after loading, as shown in figure 4.

Some fiberglass/Nylon 12 specimens were tested using emory cloth, as recommended by the American Society for Testing and Materials. Failure loads from these tests compared favorably to tests performed using end tabs. Also, the end-tabbed samples did not show a preference for

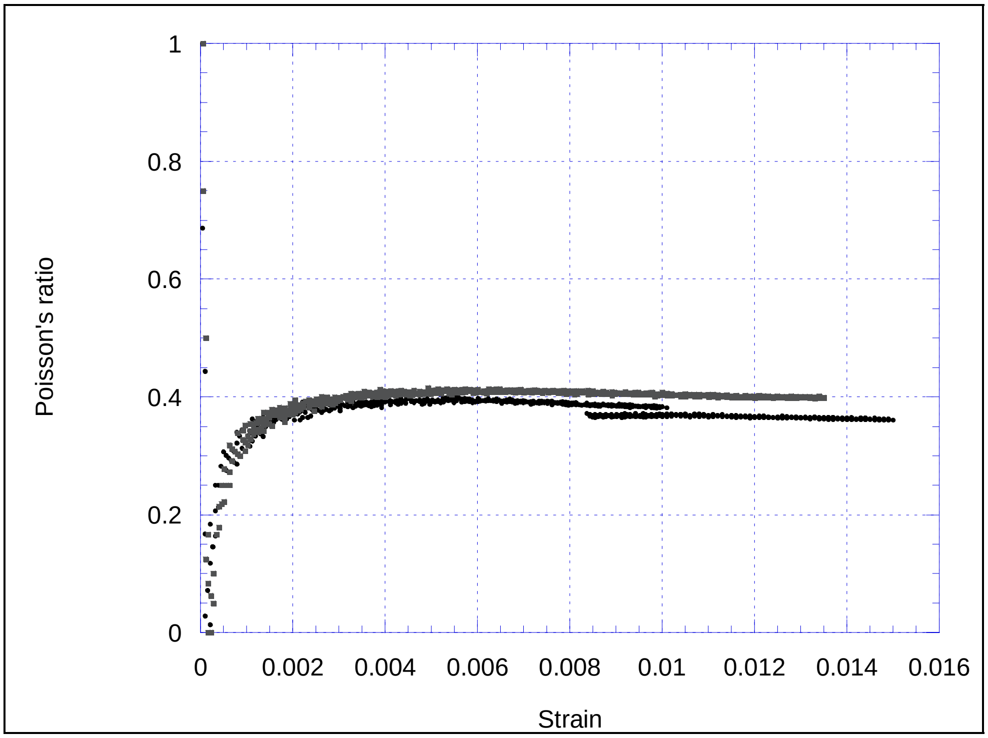

Figure 3. Examples of Poisson's ratio behavior of Nylon 12 material.

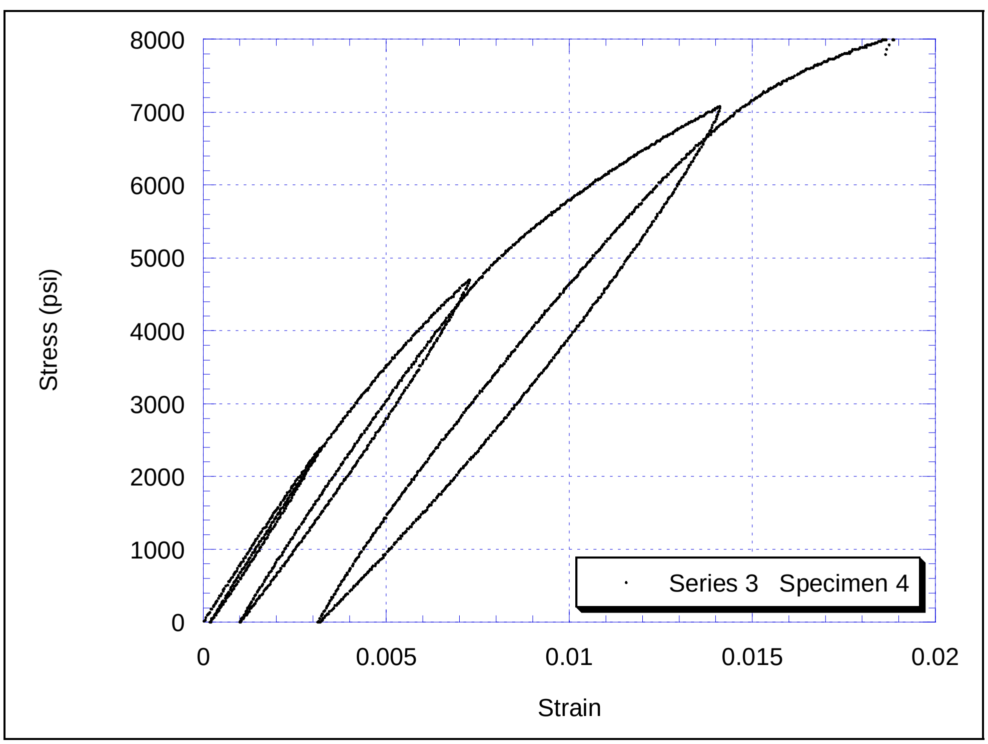

Figure 4. Example of load/unload of Nylon 12 material for residual strain characteristics.

where failure occurred, with samples failing both in the gage section and at the end tabs. This trend was also observed in the tests using the emory cloth.

Commercial data sheets on similar materials report strengths of ~20 ksi. The discrepancy between current tests and published data may be due to manufacturing differences. It has been suggested that preferential fiber alignments, which can occur easily in thin-walled injection molded parts, do not occur throughout a thicker part, such as the 0.375-in thick tube supplied for this study. Microscopy performed on the fiberglass/Nylon 12 material shows varied fiber alignment, as seen in figure 5. Some alignment occurs in the injection direction (longitudinal tube directions) near the walls of the mold. The alignment of fibers found near the inner wall can be seen to diminish to near random closer to the center of the thickness. In an effort to preserve fiber alignment, the series 3 tests employed specimens that were carefully sectioned directly from an arc section of tube. The results of this last series showed negligible benefit as a result of this method. In general, the occasional irregularities between similar specimens may be due to irregularities in the dispersion and orientation of fibers that can occur during mixing and injection.

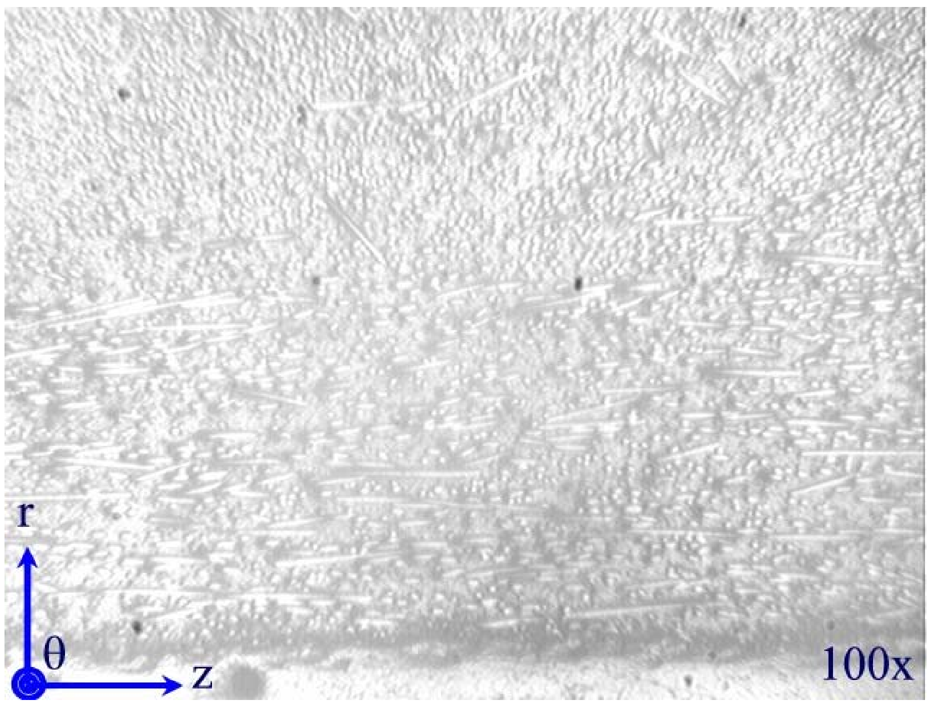

Figure 5. Micrograph of Nylon 12 material where alignment can be seen near tube inner wall in longitudinal direction. View is looking into the "theta" direction.

3.2 The 30% Fiberglass/ULTEM

Two tubes of the 30% chopped fiberglass/ULTEM were tested in this study. The first tube was machined from an extruded section. The second tube was injection molded to shape, with no

post-molding machining. This allowed for the effects of processing to be evaluated in regards to material properties.

3.2.1 Extruded Fiberglass/ULTEM

The extruded 30% chopped fiberglass/ULTEM was supplied as a 6-in long tube of 5.5-in diameter, with a 0.25-in wall thickness with end-seal chevrons. The samples were prepared using the previously outlined method, except the chevrons on the end were removed. The ultimate strength of this material is 21.5 ksi, with an initial modulus of 1 to 1.1 Msi, making it slightly stiffer but over twice as strong as the fiberglass/Nylon 12 samples. The strain capability of this system is also significantly better with a 3.1% strain to failure. The stress-strain response is similar to the fiberglass/Nylon 12, exhibiting nonlinear softening to a clean break, as shown in figure 6.

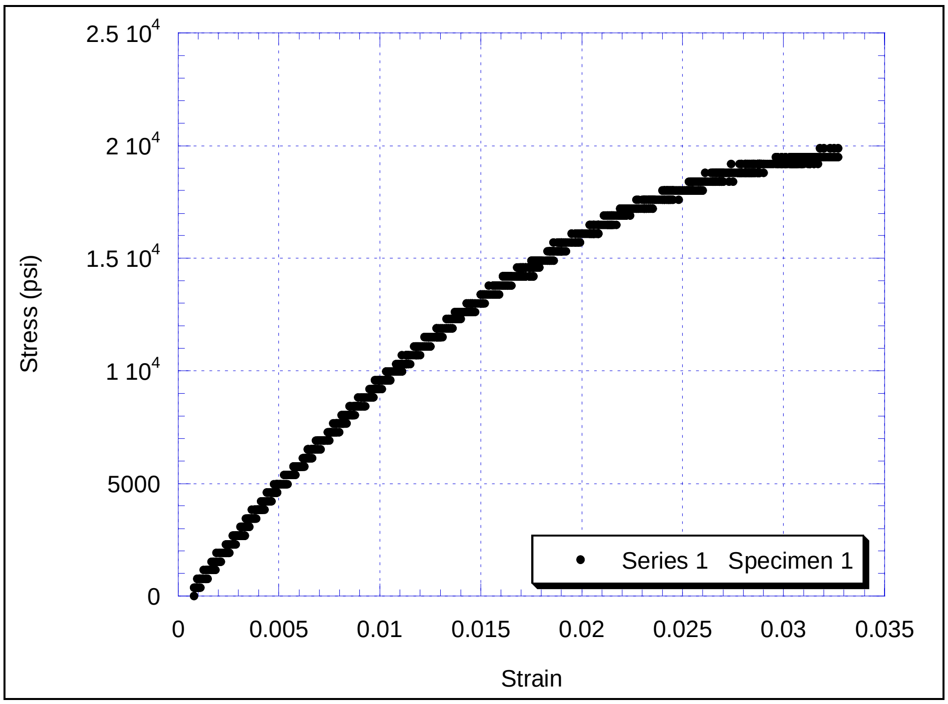

Figure 6. Representative example of extruded/machined ULTEM series results.

3.2.2 Injection-Molded Fiberglass/ULTEM

The injection-molded tube had a 6-in diameter and a 0.375-in wall thickness. Samples were prepared and tested with the method outlined for the fiberglass/Nylon 12 tube. The stress-strain results from the tension tests are shown in figure 7. The plastic strain is measured from a load/unload test. The stress-strain behavior is similar to the extruded material, but the failure properties differ. The ultimate stress is 18 ksi, and strain-to-failure is 2.4%. Both properties are lower than for the extruded version of the ULTEM material. The Poisson's ratio graph in figure 8 shows the slight difference in transverse behavior between the two types of ULTEM samples.

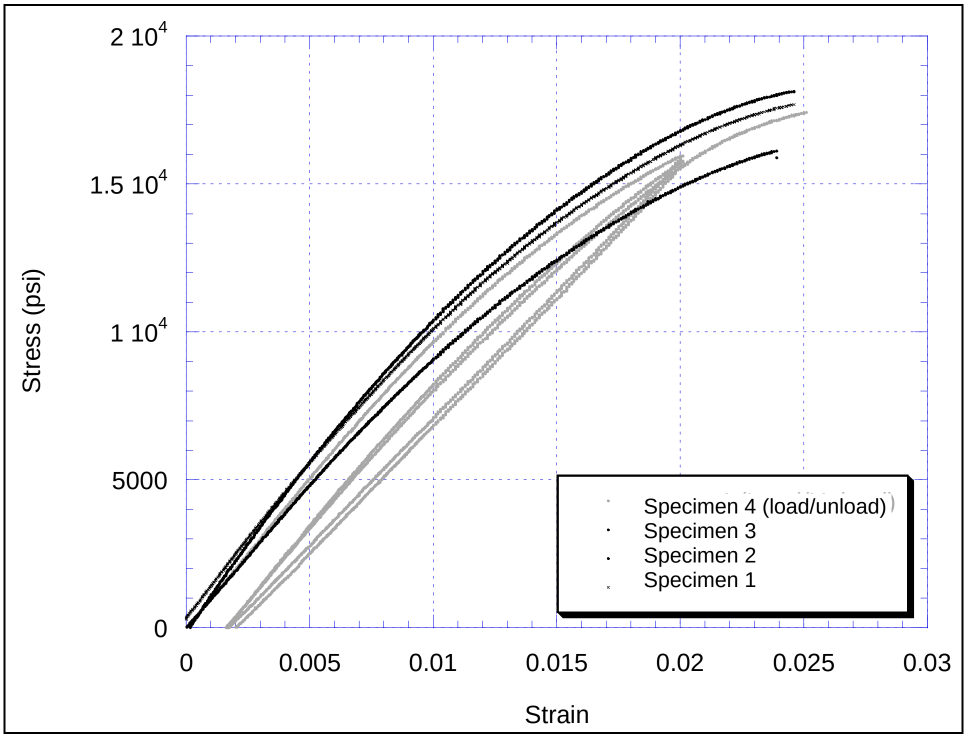

Figure 7. Summary of injection molded ULTEM series results.

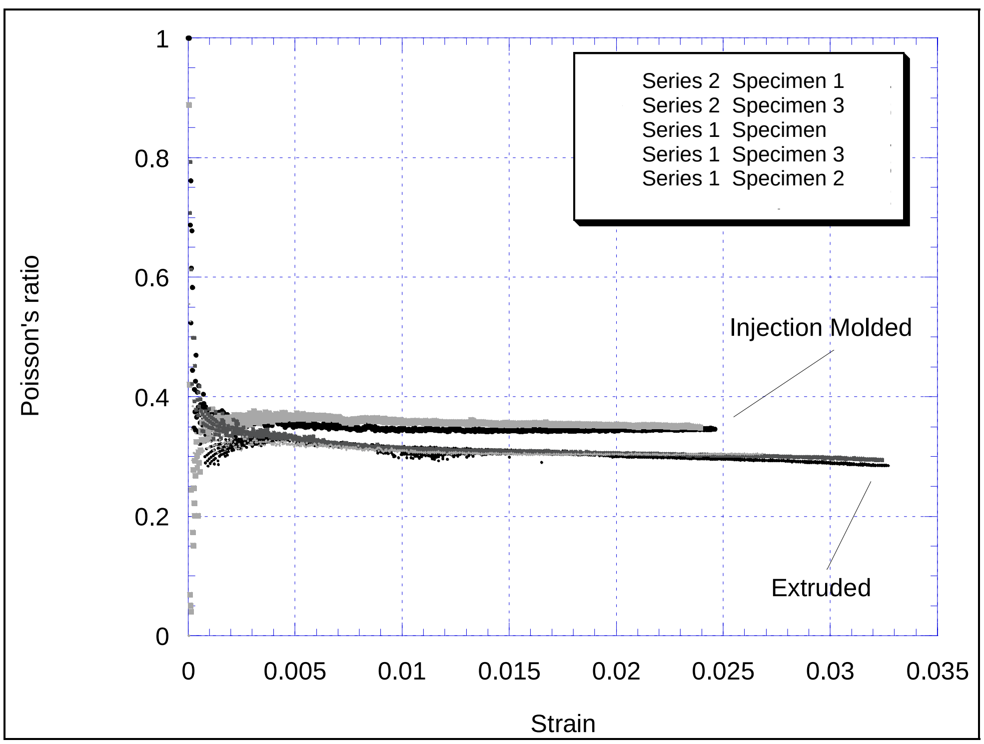

Figure 8. Summary of Poisson's ratio behavior of both ULTEM series.

3.3 Fiberglass/Urethane

A continuous fiberglass/urethane composite was also examined as a candidate cartridge case material. Four different lay-ups were tested—$[0°]_5$, $[90°]_{10}$, $[\pm 45°]_5$, and $[0°/90°]_5$. These lay-ups allowed the characterization of the longitudinal, transverse, and shear properties.

3.3.1 $[0°]_5$ Fiberglass/Urethane

The stress-strain results from tension tests on the $[0°]_5$ samples are shown in figure 9. Since the behavior of the samples is governed by the glass fibers, the stress-strain relation is basically linear, with a modulus of 6.1 Msi. The average ultimate stress is 51.8 ksi, but it should be noted that all of the samples failed at the ends with the same characteristic pattern. The self-tightening action of the Instron grips squeezed out the material between the end tabs. The end tabs pulled off, tearing out a section of the sample. A different end-tabbing scheme is required to measure actual ultimate strength. The transverse behavior is mainly due to the properties of the rubber, as evident in figure 10 where Poisson's ratio approaches 0.5.

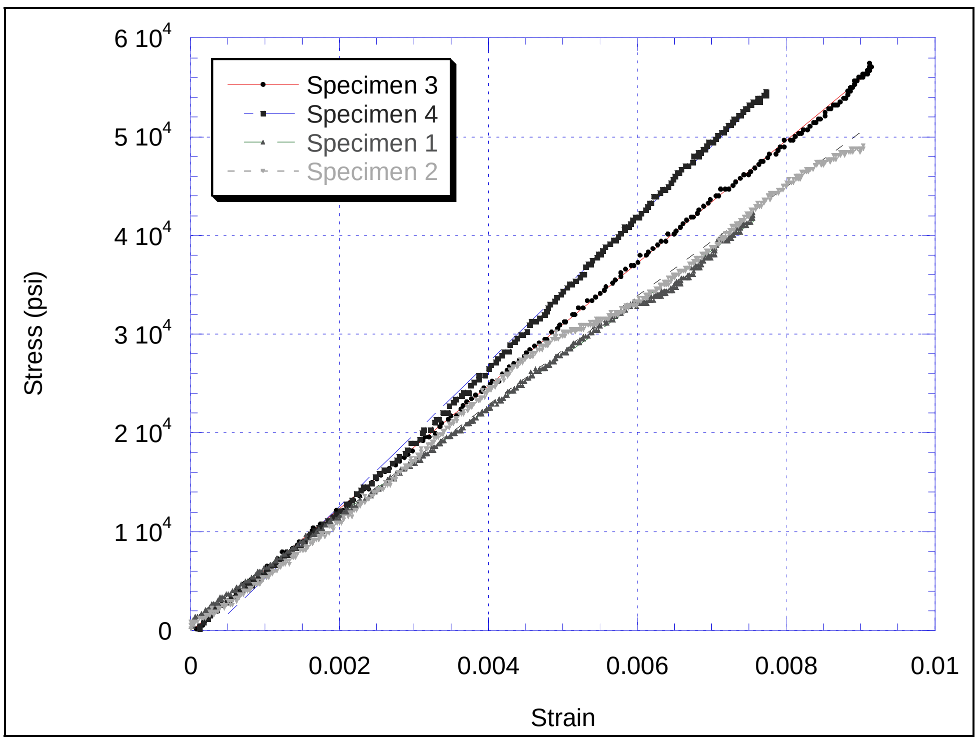

Figure 9. Summary of $[0°]_5$ urethane response obtained prior to end tab debond.

3.3.2 $[90°]_{10}$ Fiberglass/Urethane

The properties of the $[90°]_{10}$ samples are now primarily due to the rubber, with no reinforcement in the test direction. The stress-strain results are shown in figure 11, indicating a high degree of nonlinear flattening of the curve. The plot is not indicative of the failure strains, which

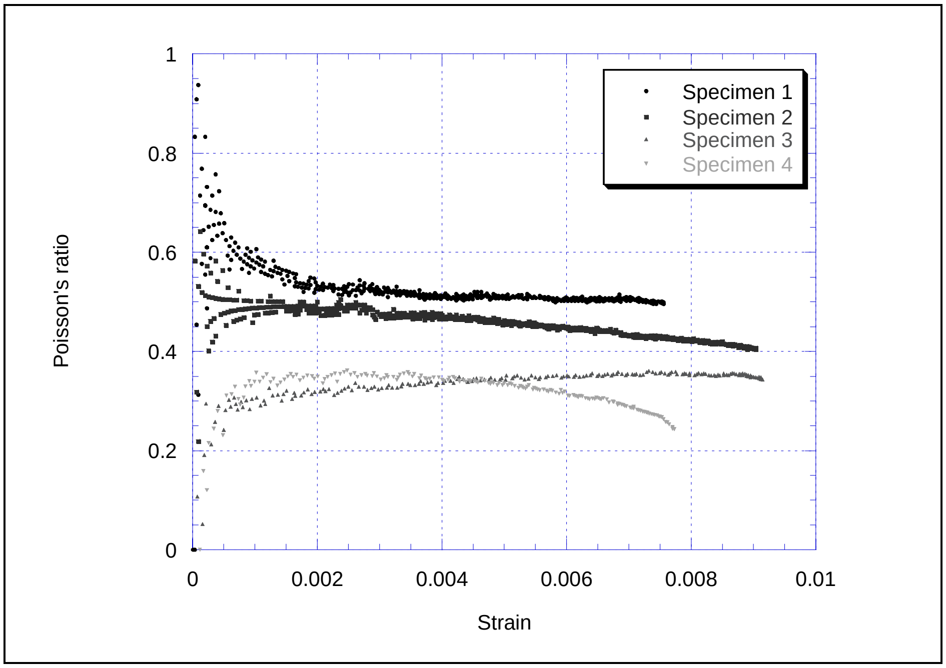

Figure 10. Poisson's ratio behavior of $[0°]_5$ urethane series specimens.

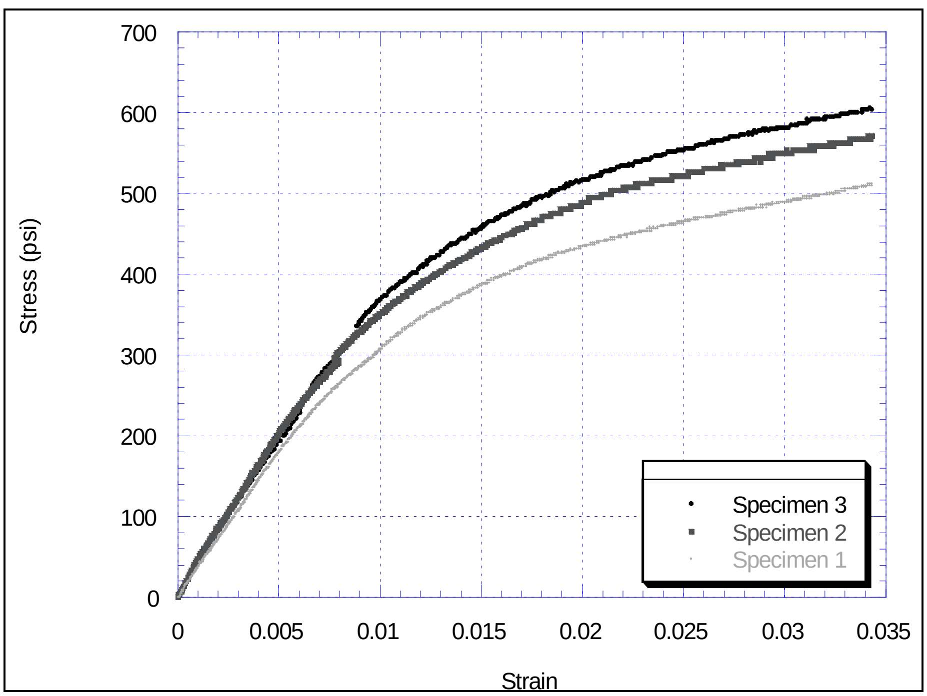

Figure 11. Initial portion of $[90°]^{10}$ urethane response. Strains exceeded gage capabilities, while loads remained low until failure.

approached 50%, because the strain gages used have a maximum strain capacity of 5%. The stress never became greater than 1 ksi. At higher strains, striations between fiber bundles became apparent on the outer surfaces until the specimens failed. Because of the transverse fibers, lateral contraction was limited, as evident in figure 12, which shows the transverse Poisson's ratio behavior of the $[90°]_{10}$.

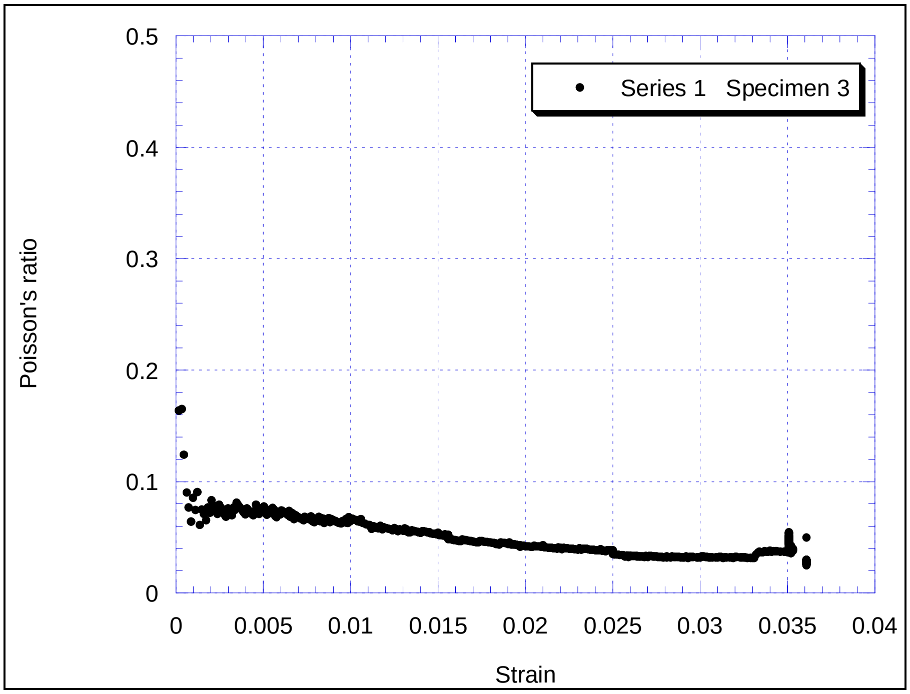

Figure 12. Example of Poisson's ratio behavior of a $[90°]_{10}$ urethane specimen. Strain gage measured lateral contraction on outer ply face, which was resisted by the alignment of the fibers in this direction. Through-thickness behavior is not represented and may differ significantly.

3.3.3 $[\pm 45°]_5$ Fiberglass/Urethane

The next lay-up tested with the fiberglass/urethane materials was a $[\pm 45°]_5$. Figure 13 shows the tensile response of a test sample. This specific lay-up allows the shear properties (G_{12}, τ_{ult}) to be measured through tension. To determine the shear stress-shear strain curves, the tensile response is transformed to the shear response using the relations $\tau_{shear} = \frac{\sigma_x}{2}$ and $\gamma_{shear} = |\varepsilon_x| + |\varepsilon_y|$.

Figure 14 shows the data from a test converted to shear components. This particular configuration exhibits a "scissoring" dominated mode of contraction, tending to rotate fibers into the test direction. A directional Poisson's ratio this large would suggest a negative ration in the through-thickness direction, correlating with the observed behavior of the cross section of the samples. Expansion in the thickness direction and high Poisson in the lateral direction produced a rounded cross section from a rectangular one.

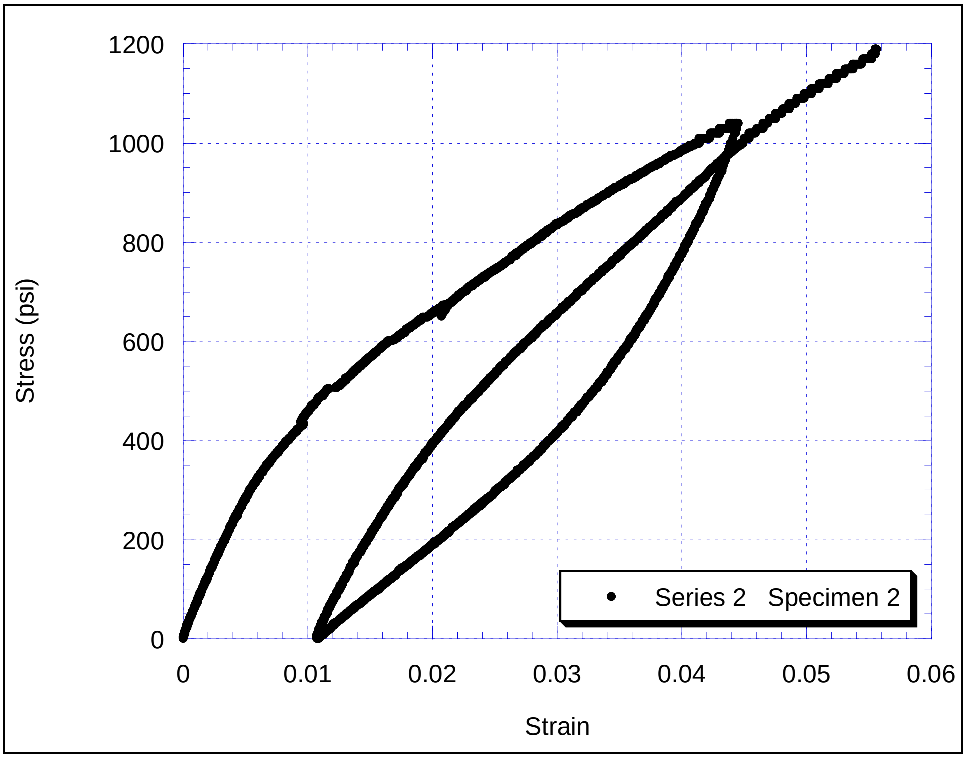

Figure 13. Tensile response of a [±45°]$_{10}$ coupon.

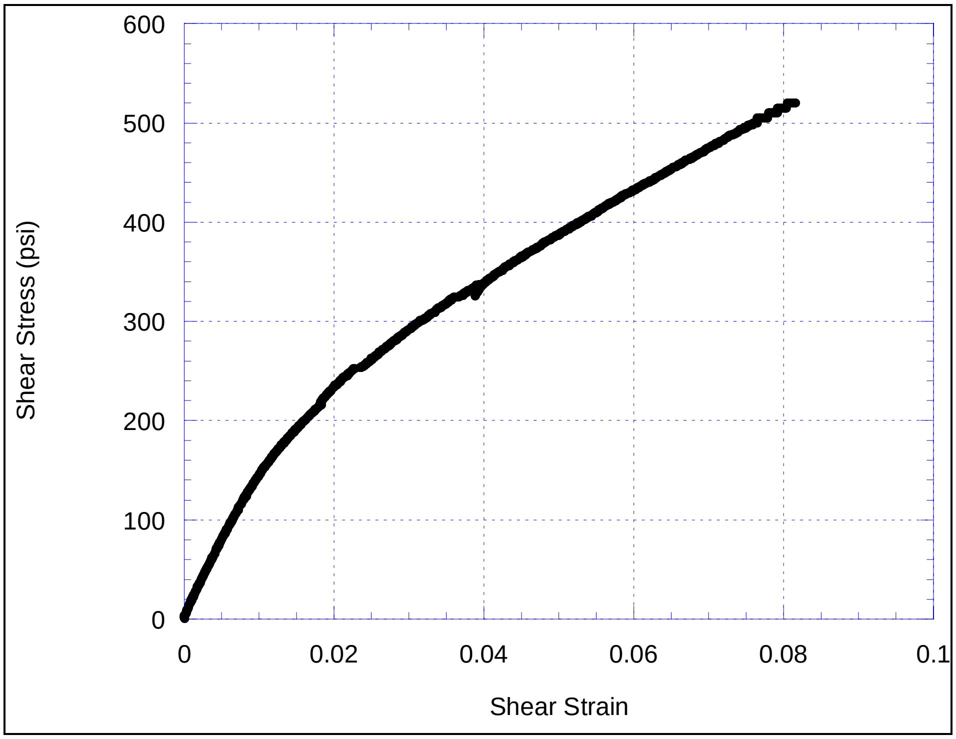

Figure 14. Reduction of [±45°]$_{10}$ tensile data into shear coordinate system.

The initial shear modulus is ~15 ksi. The maximum loads achieved are not representative of the ultimate because of the type of failure observed. At the end tabs, a ply-by-ply failure was observed as outer plies appeared to tear off. This suggests that even higher loads are possible if end effects are effectively neutralized. A Poisson's ratio near 1, evident in figure 15, demonstrates the high transverse contraction of this lay-up, which is due to the "scissoring" action of the fibers as they rotate into the test direction.

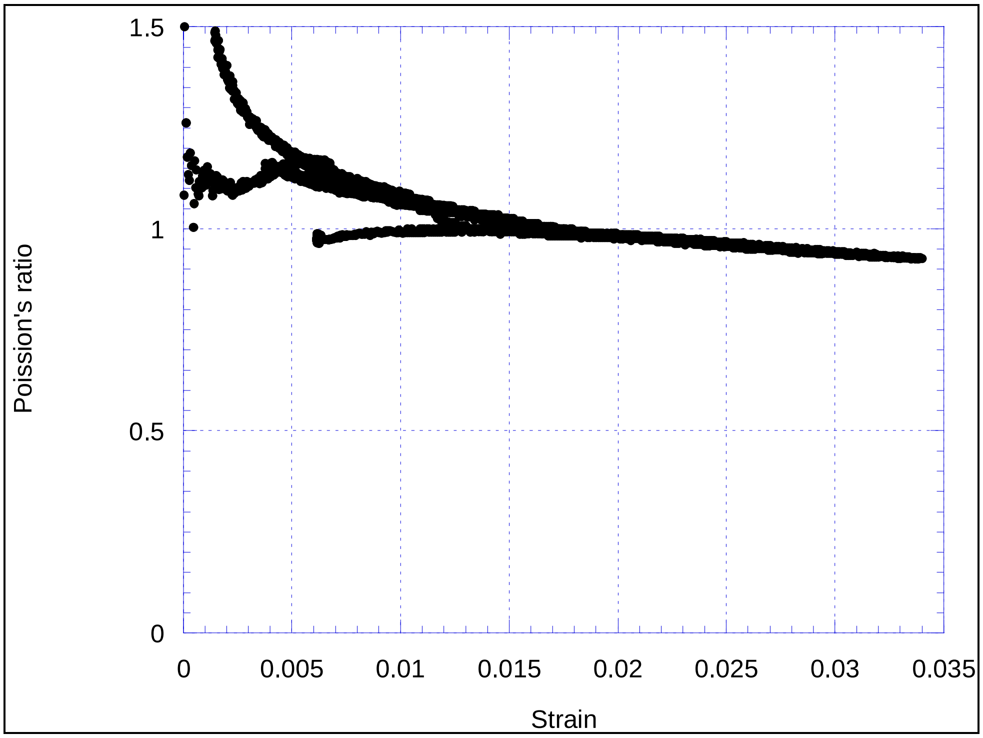

Figure 15. Apparent Poisson's ratio behavior on outer ply face of a $[\pm 45°]_{10}$ specimen.

3.3.4 $[0°/90°]_5$ Fiberglass/Urethane

The final fiberglass/urethane combination tested was a $[0°/90°]_5$ lay-up. These specimens were placed directly into the grips of the testing machine, with no end tabs. The stress-strain results are shown in figure 16, and the Poisson's ratio results are shown in figure 17.

Until failure, the samples displayed approximate linear behavior, with a modulus of ~1.8 Msi. Ply-level failure of the outer [0°] ply occurred at ~12 ksi. This is most likely from the stress concentration at the grips, causing the fibers in the outer ply to fail. Instead of the opposite [90°] face, the strain gage was mounted on this same [0°] face because of a better bonding surface. When the [0°] outer ply failed, it became partially unloaded, causing the strain to decrease (represented by the erratic behavior of the stress-strain curve above 12 ksi). The remainder of the laminate stayed intact and carried a higher load. To obtain the true ultimate characteristics of this lay-up, an effective end-tabbing scheme is again required.

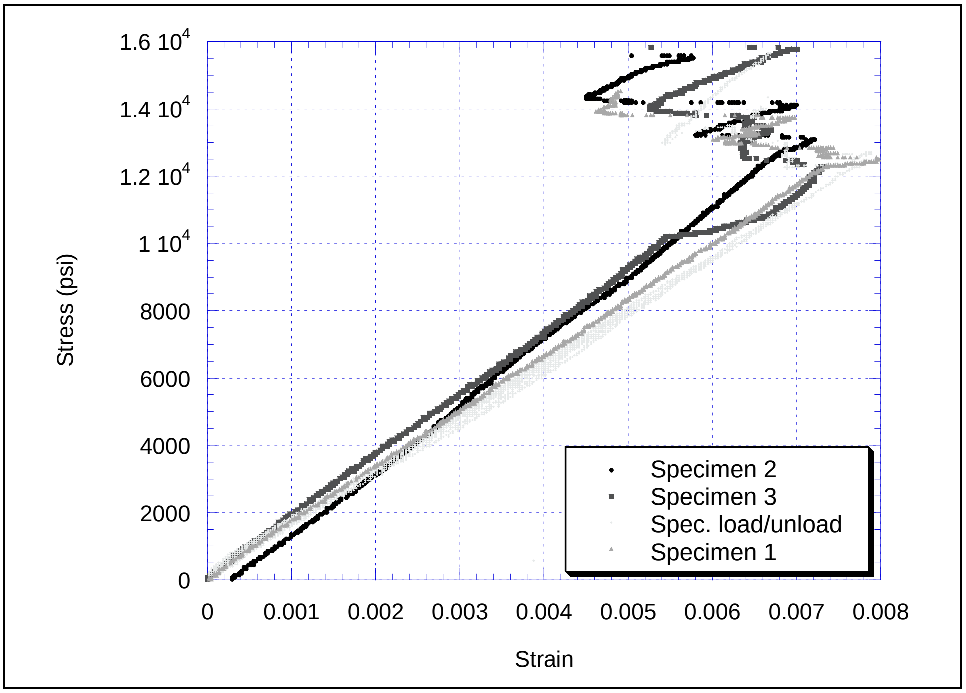

Figure 16. Stress-strain data reduced from $[0°/90°]_{10}$ tests. Odd failure region results from strain gage being mounted on outer 0° ply, which failed prior to catastrophic specimen failure. This ply partially relaxed before specimens went on to a slightly higher load.

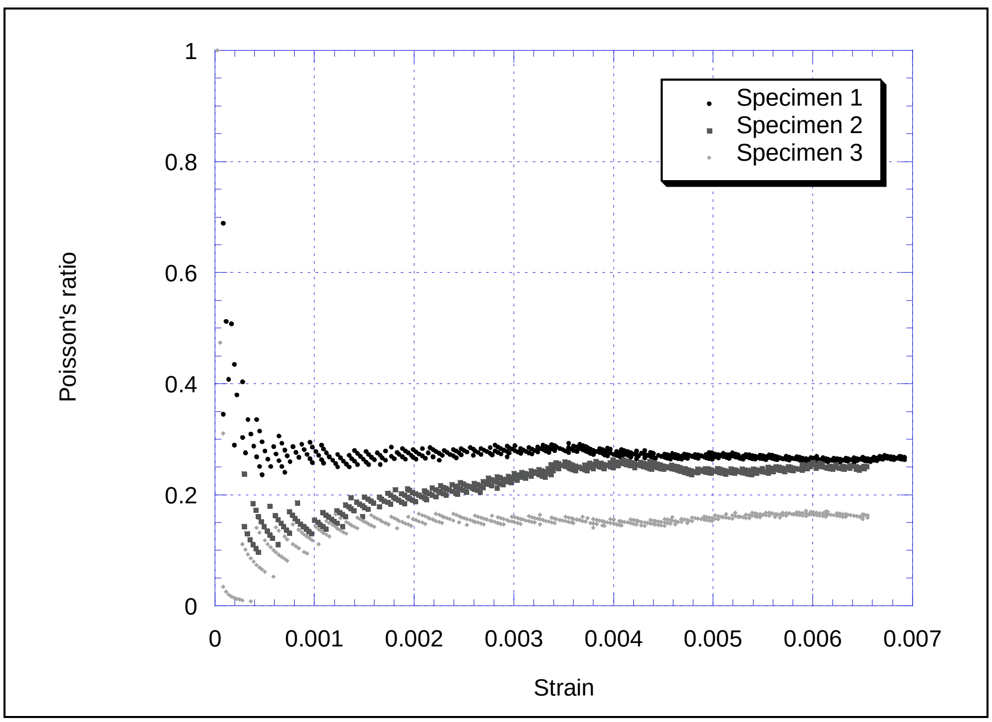

Figure 17. Observed Poisson's ratio behavior on outer 0° ply of $[0°/90°]_{10}$ samples.

It should be noted that after the initial outer [0°] ply failure and marginally increased load, all [0°] plies failed completely, as could be expected in comparison to the compliant [90°] plies. The interesting characteristic of this particular lay-up is that even after complete failure of the [0°] plies, the [90°] plies kept the coupon in one piece.

4. Conclusions

Three composite material systems, 50% chopped fiberglass/Nylon 12, 30% chopped fiberglass/ULTEM, and continuous fiberglass/urethane, were tested in order to determine basic material properties and suitability as candidates for use in the cartridge case for the CTA of the MRAAS 105-mm gun. The shape of the stress-strain curve, moduli, Poisson's ratio, failure stress and strain, and residual plastic deformation after unloading were determined. The results are presented graphically and in tabular form. These material properties are required to understand the mechanical response of the case to the loading cycle and to support the finite-element modeling of the case/chamber.

Finite-element analysis of the cartridge case in the chamber of the MRAAS swing chamber gun during a firing cycle will be presented in a separate report.[4] These analyses confirm the intuitive feeling that strength and stiffness in this case are superfluous; the gun chamber supports the load created by the high-propellant gas pressure. The most important characteristics for the case material are its ability to go to high levels of failure strain (especially in the vicinity of the discontinuation near the end seals) and to suffer minimal residual plastic strain after a firing cycle.

[4]Powers, B.; Bogetti, T.; Drysdale, W. *Finite Element Analysis of a Composite Cartridge Case in the Multi-Role Armament and Ammunition System Gun*. U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, to be published.

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1	DEUTSCHE AEROSPACE AG DYNAMICS SYSTEMS M HELD PO BOX 1340 D 86523 SCHROBENHAUSEN GERMANY

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